Automatic prospective spectroscopy VOI placement based on brain segmentation

A. J. van der Kouwe[1], M. Balasubramanian[2], E. A. Busa[1], and B. Fischl[1,3]

[1]Athinoula A. Martinos Center, Massachusetts General Hospital, Charlestown, Massachusetts, United States, [2]Department of Cognitive and Neural Systems, Boston University, Boston, Massachusetts, United States, [3]Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States

Introduction and Background

In order to detect subtle longitudinal changes in the spectrum of a given brain structure, it is important that the volume of interest (VOI) used in a magnetic resonance spectroscopy scan be defined consistently from one study of a given subject to the next. Defining these VOIs consistently across subjects would also facilitate inter-subject comparisons, e.g. comparing spectra in a diseased population to a control population. Achieving the required consistency by manually placing the VOIs is extremely difficult, due to inter- and intra-operator variability in placing a box that may optimally be tilted about three axes. Recently, an automated method was developed for consistent, prospective slice prescription for MRI scans of the brain such that all images, across subjects and sessions, are aligned to a common reference space [1]. We combine this technology with automated segmentation of subcortical structures and cortical regions [2,3] in order to automatically position a spectroscopy VOI over a given brain structure. The method was implemented on a Siemens (Erlangen, Germany) 1.5T Avanto scanner.

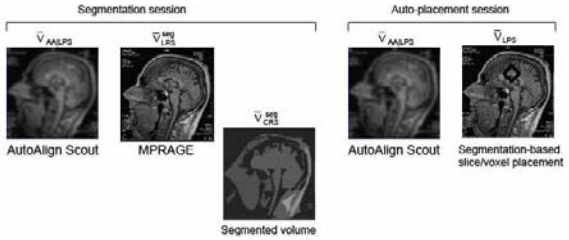

Figure 1: Acquisition and analysis procedure for automatic VOI placement. In a segmentation session, the anatomical image is acquired with AutoAlign and segmented off-line. In a further session, the subject returns and selected brain regions are mapped to the segmented volume by reference to the common AutoAlign space.

Methods

Automatic placement requires a segmented brain volume specific to the subject being scanned. Since complete automatic segmentation currently requires several hours of off-line processing, the acquisition for this purpose is done in a preparatory "segmentation session" before automatic placement is possible in later "auto-placement sessions".

Since the position of the subject will be different between sessions, we need a common reference space that relates points in the subject's brain during an auto-placement session with labeled points in the segmented brain volume. The common space is the AutoAlign atlas space, which defines a truly anatomical common coordinate system. Figure 1 shows the series of steps for automatic placement. A vector **v** referring to the position or orientation of the chosen structure is traced through the images to show how the scanner coordinates of the structure during an auto-placement session relate to the coordinates of the structure in the segmented volume. Given the AutoAlign matrices for the segmentation and auto-placement sessions, $\mathbf{M}_{AA}^{seg}$ and $\mathbf{M}_{AA}$, and the matrix $\mathbf{M}_{CRS\rightarrow LPS}^{seg}$, the relationship between $\mathbf{v}_{LPS}^{seg}$ (the voxel coordinates of a point in the segmented volume), $\mathbf{v}_{LPS}^{seg}$ (the corresponding scanner coordinates during the segmentation session), $\mathbf{v}_{AA|LPS}$ (the corresponding AutoAlign atlas coordinates) and $\mathbf{v}_{LPS}$ (the corresponding scanner coordinates during the auto-placement session) is as follows:

$$\mathbf{v}_{LPS}^{seg} = \mathbf{M}_{CRS\rightarrow LPS}^{seg}\mathbf{v}_{CRS}^{seg} \qquad \mathbf{v}_{AA|LPS} = (\mathbf{M}_{AA}^{seg})^{-1}\mathbf{v}_{LPS}^{seg} \qquad \mathbf{v}_{LPS} = \mathbf{M}_{AA}\mathbf{v}_{AA|LPS}$$

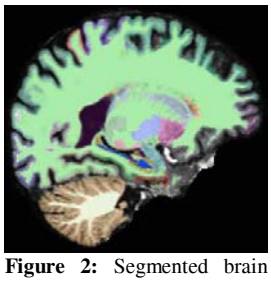

Figure 2: Segmented brain volume. Arrow denotes principal eigenvector of hippocampus in sagittal plane.

Figure 2 shows a segmented brain volume with cortical regions and subcortical structures labeled by FreeSurfer [2,3]. The scanner has access to the segmented volume as well as a lookup table that relates labels to structure names. The segmented volume header contains the AutoAlign matrix and segmentation CRS to scanner LPS matrix. The scanner operator selects the structure or set of structures of interest on the scanner UI from an alphabetized list of structures that occur in the segmented volume. The scanner then calculates the VOI and displays the proposed placement to the operator. The placement and orientation are calculated using an algorithm selected by the operator, and the volume of the structure(s) of interest is calculated. One algorithm calculates the centroid and covariance matrix of the structure to determine the center and principal axes. The second algorithm calculates the tightest fitting oriented bounding box, using a fast approximate method developed by Barequet and Har-Peled [4].

Results and Conclusion

We scanned a subject and segmented the MPRAGE to obtain the segmented volume. In a second session, the subject returned, and the right hippocampus was selected on the UI as the target structure for spectroscopy. Figure 3 (left) shows the proposed VOI displayed on the scanner UI using the tightest fitting bounded box enclosing the right hippocampus along with the measured spectrum. The subject was removed from the scanner and reintroduced with a deliberately different head position. Figure 3 (middle) shows the VOI and spectrum. For comparison, the placement and spectrum collected with the VOI shifted slightly inferior is shown in Figure 3 (right). We also collected a clean spectrum in white matter. Spectra were collected with a 6:48 minute modified STEAM sequence. The calculated VOI dimensions were 45x23x11 mm^3 and the right hippocampus volume for this subject was 3,636 mm^3, therefore 32% of the VOI contained hippocampus, and 100% of the hippocampus was contained in the VOI. This is the most efficient possible given the requirements of a rectanguloid bounding box and 100% hippocampal inclusion.

Spectroscopy in the hippocampus is challenging because it is close to a region of susceptibility change where it is difficult to accurately correct the B0 field by shimming. Misaligning the VOI by a few millimeters in the inferior direction can cause a catastrophic change in the acquired spectrum as shown in Figure 3 (right). In this case, substantial water signal remained unsuppressed. Our automatic VOI placement method consistently placed the VOI from one session to another, yielding consistent NAA/creatine ratios (1.13 and 1.09 vs 0.081 for the displaced VOI and 1.99 for the white matter VOI). The method was able to select the tightest-fitting box, tilted about all axes, thus minimizing contributions to the spectrum from surrounding tissue. Accurate placement of an oblique box by a human operator is challenging. Automatic VOI placement may be useful in longitudinal studies of subjects such as Alzheimer's patients, where consistent and accurate VOI placement is critical for measuring relevant changes over time. In future work, VOI computation from data collected in the same session will be explored.

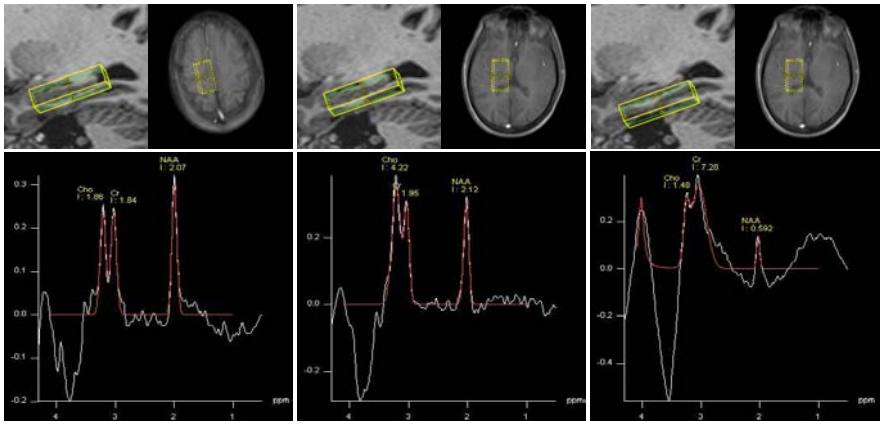

Figure 3: VOI positions (above) and corresponding spectra (below), for first auto-placement session (left), second auto-placement session (middle) and session with manual offset (right).

Acknowledgement

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